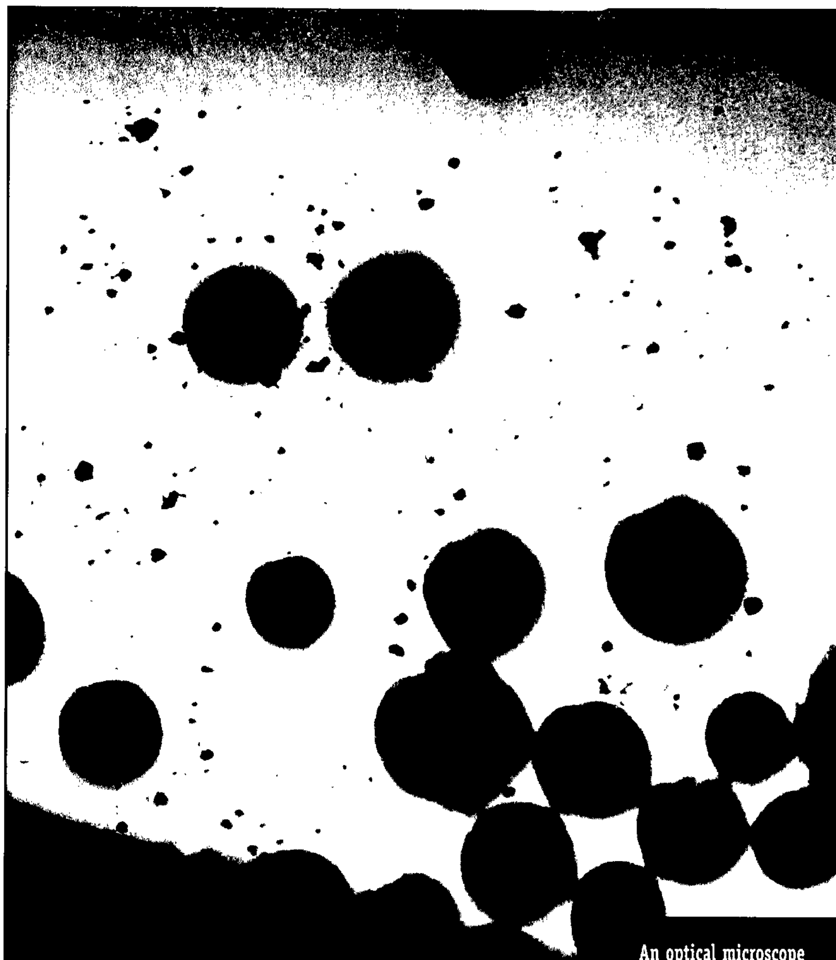
AIR FORCE OFFICE of SCIENTIFIC RESEARCH [AFOSR]

Manager of the Basic Research Investment for the Air Force

JAN FEB 01

Research Highlights



An optical microscope image in through-transmission of a self-healing polymer with the microcapsules clearly evident in red (the healing agent was mixed with a red dye for the visualization), the catalyst in black (the dark specs in the image), and the solid red line across the center of the image indicates the position of the crack front. The healing agent has penetrated the entire crack plane since it shows solid red behind the crack front.

AFOSR Funds the Development of a Self-Healing Plastic

AFOSR-sponsored researchers at the University of Illinois at Urbana-Champaign (UI) recently reported significant progress in the development of a self-healing plastic. The material — consisting of a microencapsulated healing agent and a special catalyst embedded in a structural composite matrix — could increase the reliability and service life of thermosetting polymers used in a wide variety of applications ranging from microelectronics to aerospace.

Inspired by biological systems in which damage triggers an autonomic healing response, researchers at the University of Illinois have developed a synthetic material that can heal itself when cracked or broken. The results were published in the Feb. 15 issue of the journal *Nature* and led to extensive national media coverage.

The payoff of this research could be significant to the Air Force because of the many polymer-based composites in our weapons systems. Frequently, structural damage, in the form of microcracks, develops deep within the aircraft where detection is difficult and repair becomes almost impossible. However, with this potential new material, the repair process would become transparent, since it begins as soon as a microcrack forms. The end result would be more durable aircraft/spacecraft.

"Once cracks have formed within typical polymeric materials, the integrity of the structure is significantly compromised," said Scott White, a professor of aeronautical and astronautical engineering at UI and lead author of the paper published in *Nature*.

When the material cracks, the microcapsules rupture and release the healing agent into the

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Professor Scott White

The UI professor of aeronautical and astronomical engineering is the leader of the team that has developed a synthetic material that can heal itself when cracked or broken.

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damaged region through capillary action. As the healing agent contacts the embedded catalyst, polymerization initiation bonds the crack's face closed.

Because microcracks are the precursors to structural failure, the ability to heal will enable structures that last longer and require less maintenance. Filling the microcracks may also mitigate the harmful effects of environmentally assisted degradation such as moisture swelling and corrosion cracking. This technology could increase the lifetime of structural components, perhaps by as much as two or three times.

Additionally, the ability to self-repair and restore structural integrity could extend the lifetimes of printed circuit boards, where microcracks can lead to both mechanical and electrical failure.

One of the many challenges the researchers faced in developing the material was obtaining the proper size of microcapsules. They currently use spheres about .004 inches in diameter. Larger spheres could weaken the matrix, and work continues on creating ever-smaller sphere capsules. Researchers had to determine the correct shell thickness to ensure that the capsules would open under the appropriate stress. Capsule walls that are too thick may not rupture when the crack approaches, while capsules with walls that are too thin might break during processing.

Dr. White and his team received initial and some follow-on funding from a UI Critical Research Initiatives grant. Then in 1999, AFOSR's Aerospace and Materials Sciences Directorate awarded the UI research team a three-year grant.

"The Air Force Office of Scientific Research was the first major funding agency to step forward. Without AFOSR's grant, we wouldn't have been able to assemble the critical mass of people to work on this project," said White.

Although the research may be five to ten years away from playing a significant role in an operational system, the preliminary results provide promising possibilities for the Air Force and potential commercial applications as well.

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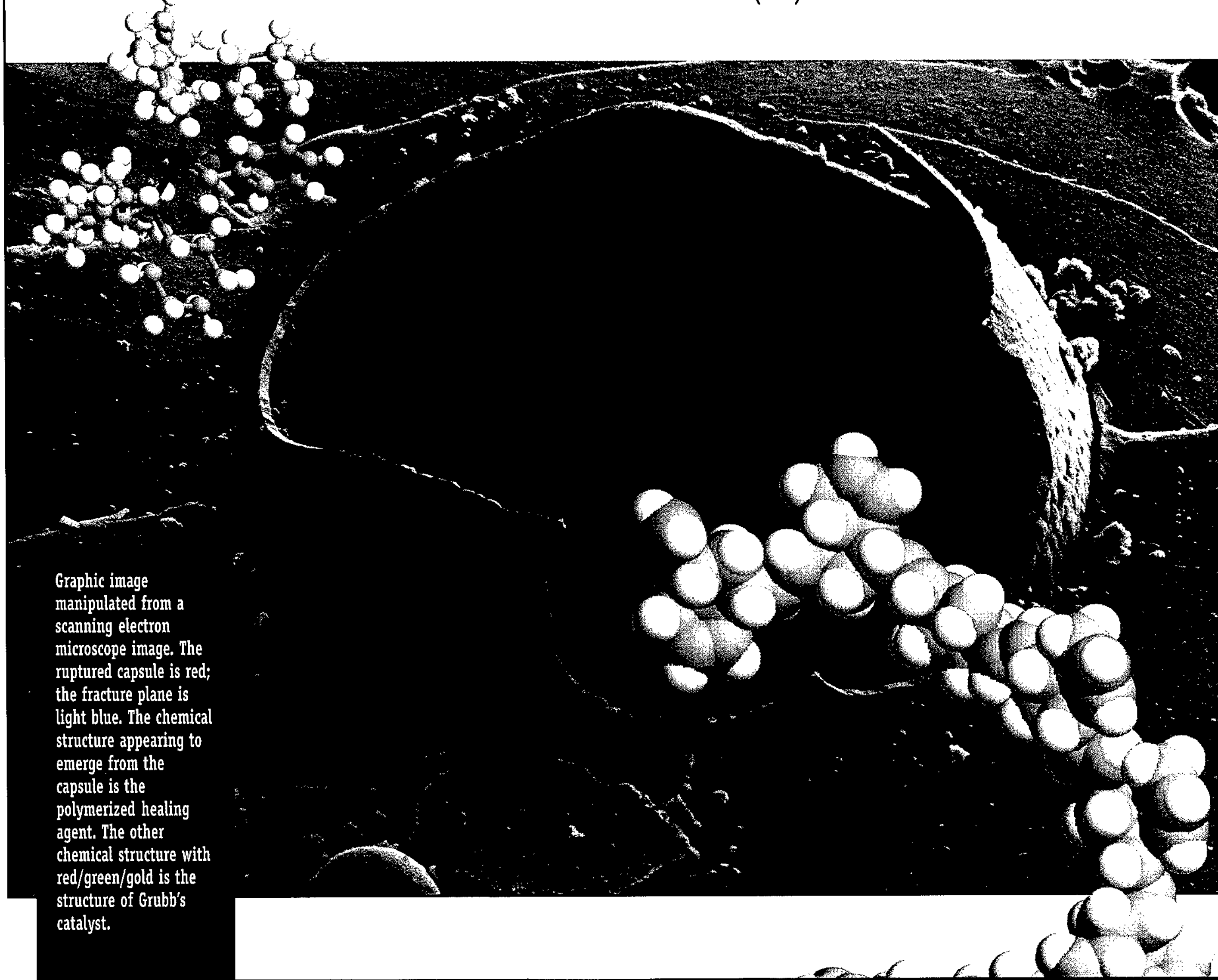
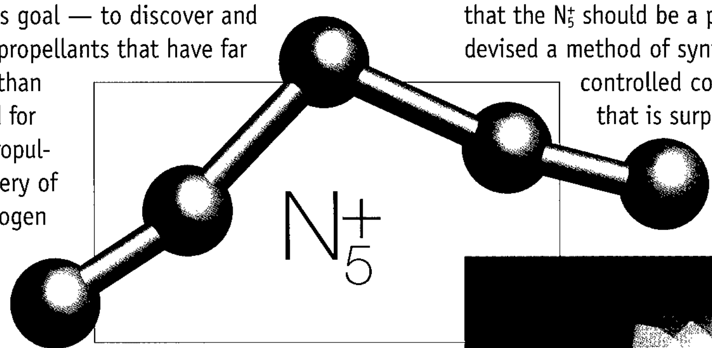


Graphic image manipulated from a scanning electron microscope image. The ruptured capsule is red; the fracture plane is light blue. The chemical structure appearing to emerge from the capsule is the polymerized healing agent. The other chemical structure with red/green/gold is the structure of Grubb's catalyst.

Revolutionary New Rocket Propellants—N_5^+

In the late 1980s, the Air Force Office of Scientific Research (AFOSR) sponsored the High Energy Density Matter (HEDM) group, which now resides in the Space and Missile Propulsion Division of the Air Force Research Laboratory's (AFRL) Propulsion Directorate at Edwards Air Force Base. The group's goal — to discover and develop new chemical propellants that have far greater energy density than materials currently used for rocket and spacecraft propulsion. The recent discovery of a new high energy nitrogen candidate has met the goal.



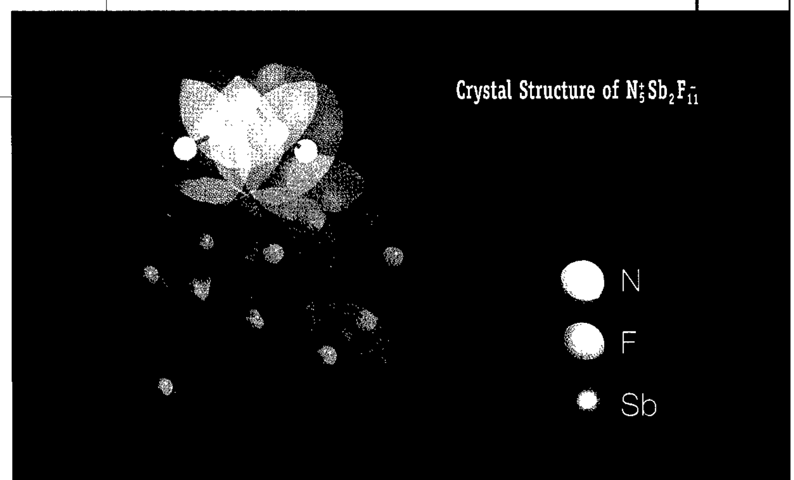
This high pay-off endeavor is being led by a group of about fifteen researchers with expertise in organic chemistry, inorganic chemistry, physical chemistry, and chemical physics. They employ a highly synergistic blend of experimental, theoretical, and computational techniques to identify target compounds, attempt their synthesis on a laboratory scale, characterize new materials, and perform larger-scale synthesis of promising new species for formulation and testing in subscale rocket devices.

These much sought after advanced chemical propellants can be utilized across the entire range of chemical propulsion applications, including liquid hydrocarbons for heavy-lift boosters, cryogenic propellants for upper stages, liquid and solid oxidizers for boost and upper stages, and monopropellants for upper stages and satellite propulsion. Therefore, the desire to maximize the amount of payload carried by a particular vehicle and minimize the amount of weight devoted to propellants and tankage, leads naturally to the need for propellants with greater energy per volume/weight.

In a revolutionary step towards that goal, the AFOSR-AFRL-HEDM team, led by Dr. Karl Christie and Dr. Jeffrey Sheehy, has prepared a new energetic chemical species, composed entirely of nitrogen atoms — N_5^+. The historical significance of this discovery becomes apparent when one realizes that until this recent discovery, the only two cases of all-nitrogen compounds being isolated occurred in 1772 and 1890. This new breakthrough opens the door to the development and exploration of a new class of polynitrogen compounds that could provide extremely energetic, yet environmentally benign, propellants.

Over the past decade, researchers (many of them part of the AFOSR-AFRL-HEDM program) have done basic research that led to the prediction that several all-nitrogen compounds should be stable enough to exist. However, these theoretical compounds had never been synthesized. So, in 1998, AFOSR and DARPA formed a partnership with a goal of preparing polynitrogen compounds. The HEDM group was selected to pursue the preparation of all-nitrogen compounds by novel applications of chemical theory and inorganic synthesis.

Using quantum-chemical calculation employing methods and software developed under AFOSR sponsorship, Sheehy predicted that the N_5^+ should be a particularly stable compound. Christie devised a method of synthesizing an N_5^+ salt under carefully controlled conditions. The result was a white powder that is surprisingly stable and which can be stored indefinitely at room temperature. Following the initial synthesis of the new compound, process improvements have been made such that gram-scale quantities can be produced in less than a week, representing an order of magnitude in scale up and cost reduction. Work continues to explore the use of these discoveries relative to monopropellants with over 200% greater energy density than the currently utilized hydrazine, a widely used but highly toxic compound.



Crystal Structure of $N_5^+Sb_2F_{11}^-$

"AFOSR was there from the beginning. It was largely through AFOSR's funding that this program was able to grow. In addition, AFOSR recognized computational chemistry techniques that were the best to guide the experimental efforts," Sheehy said.

As only the third all-nitrogen species to be isolated in bulk form, and the first in over 100 years, the AFRL discovery of N_5^+ has been widely acclaimed internationally, having been reported even in the popular press, including the *New York Times* and the *London Times*. The weekly publication of the American Chemical Society, *Chemical & Engineering News,* selected the synthesis of an N_5^+ salt as one of the top five achievements in chemistry in 1999. This revolutionary achievement by the AFOSR-AFRL-HEDM group and DARPA is a huge step in advanced chemical propellants to power the future Aerospace Force.

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Air Force selects Dr. Lyle H. Schwartz

The Air Force Research Laboratory (AFRL) recently announced that the Air Force has selected Dr. Lyle H. Schwartz as the new director of the Air Force Office of Scientific Research (AFOSR). This appointment became effective 25 February 2001. Schwartz, a member of the Senior Executive Service since 1984, has served as director of AFOSR's Aerospace and Materials Sciences directorate since 1999.

Dr. Lyle H. Schwartz

"Dr. Schwartz was chosen from some tough competition — his unique talents made him stand out from his competitors and his strong desire to help AFOSR excel will make him a great director," said Brig. Gen. Paul Nielsen, AFRL commander.

The AFOSR Director guides the management of the entire basic research investment for the U.S. Air Force. The director leads a staff of over 150 scientists, engineers, and support personnel located in Arlington, Va. and the two foreign technology offices in London and Tokyo. The AFOSR director is charged with maintaining the technological superiority of the U.S. Air Force. Each year, AFOSR selects, sponsors, and manages revolutionary basic research relevant to Air Force needs. AFOSR's investment in basic research programs is distributed across 300 academic institutions, 145 industry contracts, and more than 150 internal AFRL research efforts.

Schwartz brings many years of scientific leadership experience and an extensive list of accomplishments to his new position. He earned his bachelor's degree in science engineering in 1959 and doctor of philosophy in materials science degree in 1964 from Northwestern University in Evanston, Ill. From 1964 to 1984, he was a professor of materials science and engineering at Northwestern University. In addition to teaching, from 1979 until 1984, he was the director of the Materials Research Center at Northwestern University. From 1984 to 1997, he served as director of the Materials Science and Engineering Laboratory at the National Institute of Standards and Technology in Gaithersburg, Md. In 1998 he became president of the Associated Universities Inc., in Washington, D.C.

Schwartz is known for his contributions in the areas of phase transitions in iron alloys; applications of Mossbauer Spectroscopy; x-ray and neutron diffraction; characterization of catalysts; and policy issues concerning materials science and engineering. He has written more than 85 technical papers and is co-author of two textbooks in the field of materials science and engineering. He is a member of the National Academy of Engineering.

Schwartz will replace Dr. Joseph F. Janni, who was the director of AFOSR from October, 1996 to February, 2001.

Research Highlights

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AFOSR would like to thank James Kloeppel, Physical Sciences Editor, University of Illinois News Bureau, and Ms. Nahaku McFadden for their assistance in making this issue possible.

Research Highlights is published every two months by the Air Force Office of Scientific Research. This newsletter provides brief descriptions of AFOSR basic research activities including topics such as research accomplishments, examples of technology transitions and technology transfer, notable peer recognition awards and honors, and other research program achievements. The purpose is to provide Air Force, DoD, government, industry and university communities with brief accounts to illustrate AFOSR support of the Air Force mission. *Research Highlights* is available on-line at:

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